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TITLE:

BUILDING 059—NORTH TEST CELL, CAST-IN-PLACE CONCRETE SHIELD REMOVAL

-APPROVALS-

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ABSTRACT

As part of the Building 059 Phase II Reactor Test Cell Remediation Program, a cast-in-place high density concrete shield is to be removed. A trade study of various concrete demolition scenarios was performed in order to select the most appropriate demolition method for the project. The shield installation design and history were reviewed, a checklist of demolition method selection criteria was developed, and a list of candidate demolition methods was established.

Each method was then studied in sufficient detail to construct one or more applications for this shield removal task and identify associated costs, schedules, manpower needs and radiation exposure potential. Methods were eliminated as technical limitations for this application were recognized.

The list was finally reduced to seven entries which were then ranked by cost, schedule, and as low as reasonably achievable (ALARA) radiation exposure consideration categories. An overall ranking order and relative ranking numeric values were developed. Recommendations were made for continued study in several areas. The demolition method recommended for this application is a remotely operated hydraulic Breaker Ram.

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1.0 PURPOSE

The purpose of this Trade Study is to:

- Establish a set of selection criteria for the cast-in-place concrete shield demolition and disposal (D&D) methods to be used, based upon review of the Building 059 current and scheduled remediation status, the planned demolition sequences, and the regulatory requirement boundaries.
- Identify candidate D&D method options based upon review of Department of Energy (DOE) Remedial Action and Decommissioning Programs information, International Atomic Energy Agency (IAEA) reports, and industry and Energy Technology Engineering Center (ETEC)/Rockwell in-house information sources.
- Evaluate the shield demolition options against these selection criteria and identify the best methods for the shield removal.
- Recommend a shield removal method.

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2.0 OBJECTIVE

The objective of this study is the selection of suitable concrete shield removal methods which will permit completion of this phase of the Building 059 Remediation Program. Primary considerations are the present state of remotely performed demolition technique development, ALARA, and cost.

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3.0 BACKGROUND AND HISTORY

The SNAP Ground Prototype Test Facility, Building 059, is located in the Burro Flats area of the Rocketdyne Santa Susana Field Laboratory (SSFL), near Chatsworth, California. The Reactor Test Facility portion of the building was constructed in 1962 and modified during 1964–1965 for SNAP 8 reactor tests. (See Figures 1 and 2.) These tests were completed in 1970, the reactor test unit was removed, and the test cell was sealed with a welded cover.

The reactor cell remained closed and sealed until 1987, except for necessary annual safety inspections and radiological surveys, and the removal of most of the reactor test equipment in the mid 1970s. The 1987 inspections revealed indications of possible facility structural deterioration and the Building 059 Vault Remediation Program was initiated.

Phase I of this program, the Pipe Chase Room (PCR) Remediation Project, which included removal of irradiated shielding sand and the vacuum duct from the PCR, has been successfully completed.

Phase II, currently under way, is separated into two parts. Phase IIA includes removal of the remaining well-defined test cell components and structures. One of these structures is the cast-in-place shield. Its removal will permit Phase IIA to be completed and the definition of the Phase IIB scope of work for site restoration to be initiated.

A detailed description and technical details of the shield structure are given in References 1 and 2. The radiological characterization of Building 059 for Phase II is presented in Reference 3, where the calculated radiation levels as of December 1989 for three test cell locations are as shown below:

		Calculated R/hr
Case 6	Center of test cell with vessel removed	1.7
Case 7	1 ft from concrete shield at cell mid height with vessel removed	2.8
Case 8	1 ft from floor of cell with vessel removed	3.4

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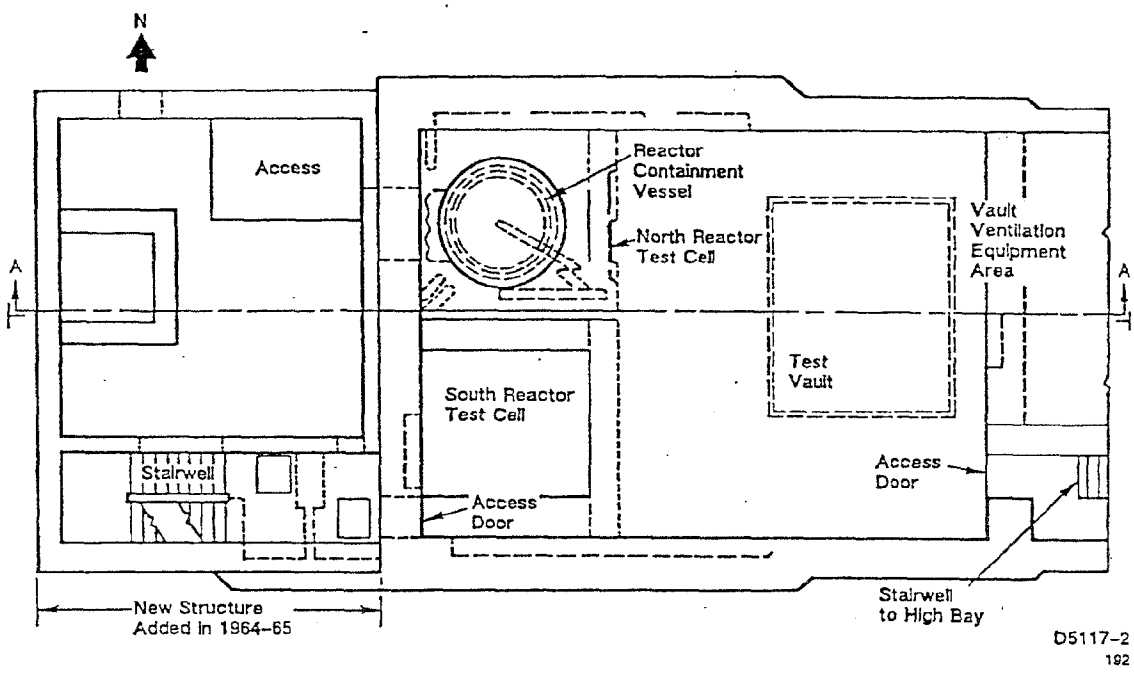

Figure 1. Plan View—Building 059 Test Vault

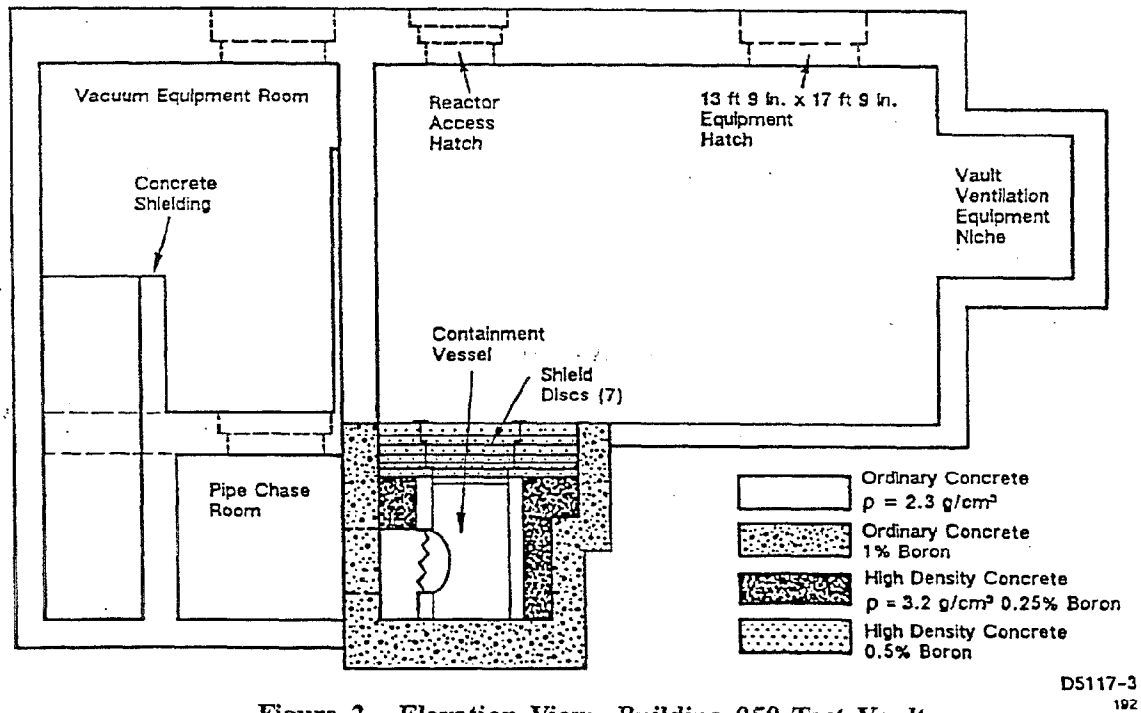
Vacuum Equipment Room
Reactor Access Hatch
13 ft 9 in. x 17 ft 9 in. Equipment Hatch
Concrete Shielding
Vault Ventilation Equipment Niche
Containment Vessel
Shield Discs (7)
Pipe Chase Room
Ordinary Concrete ρ = 2.3 g/cm³
Ordinary Concrete 1% Boron
High Density Concrete ρ = 3.2 g/cm³ 0.25% Boron
High Density Concrete 0.5% Boron
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Figure 2. Elevation View—Building 059 Test Vault

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These radiation levels following completion of the vessel removal dictate that remote demolition techniques be employed wherever possible for the shield removal to be consistent with the ALARA radiation exposure policy.

Figure 3 is an isometric representation of this shield, which partially fills the test cell space between the 6-ft-diameter vacuum vessel OD and the cell wall steel liner. The shield is made of reinforced, high-density (228-lb/ft3) borated (0.25%) concrete. It also contains many cooling coils, instrument thimbles, vent ducts, thermocouples, and conduit embedments, as detailed in Reference 2. The 5/8-in.-diameter by 0.065-in.-wall Type 304 stainless steel cooling coils are spaced 4 in. apart and are embedded approximately 2 in. from all of the exposed inside concrete surfaces. Standard 1/2-in.-thick expansion felt is located between the shield outer concrete surface and the cell liner on the south and west cell walls. On the cell floor and the north and east walls the shield concrete is in direct contact with the steel liner. This structure contains approximately 25 yd3 of concrete and has a total weight of approximately 75 tons.

A stainless steel I-beam and channel structure is bolted to the cast-in-place concrete shield. This structure supports the seven 6-in.-thick layers of removable precast concrete shield blocks which surround the upper (lid) portion of the vacuum vessel cavity. (See Figures 3 and 4.) The inside dimensions of the shield blocks are stepped to match the vessel steps, and each block contains lifting lug provisions for block removal. (See Drawings 7568-93004 and 93006.) This support structure and the shield blocks must be removed as part of the shield D&D task.

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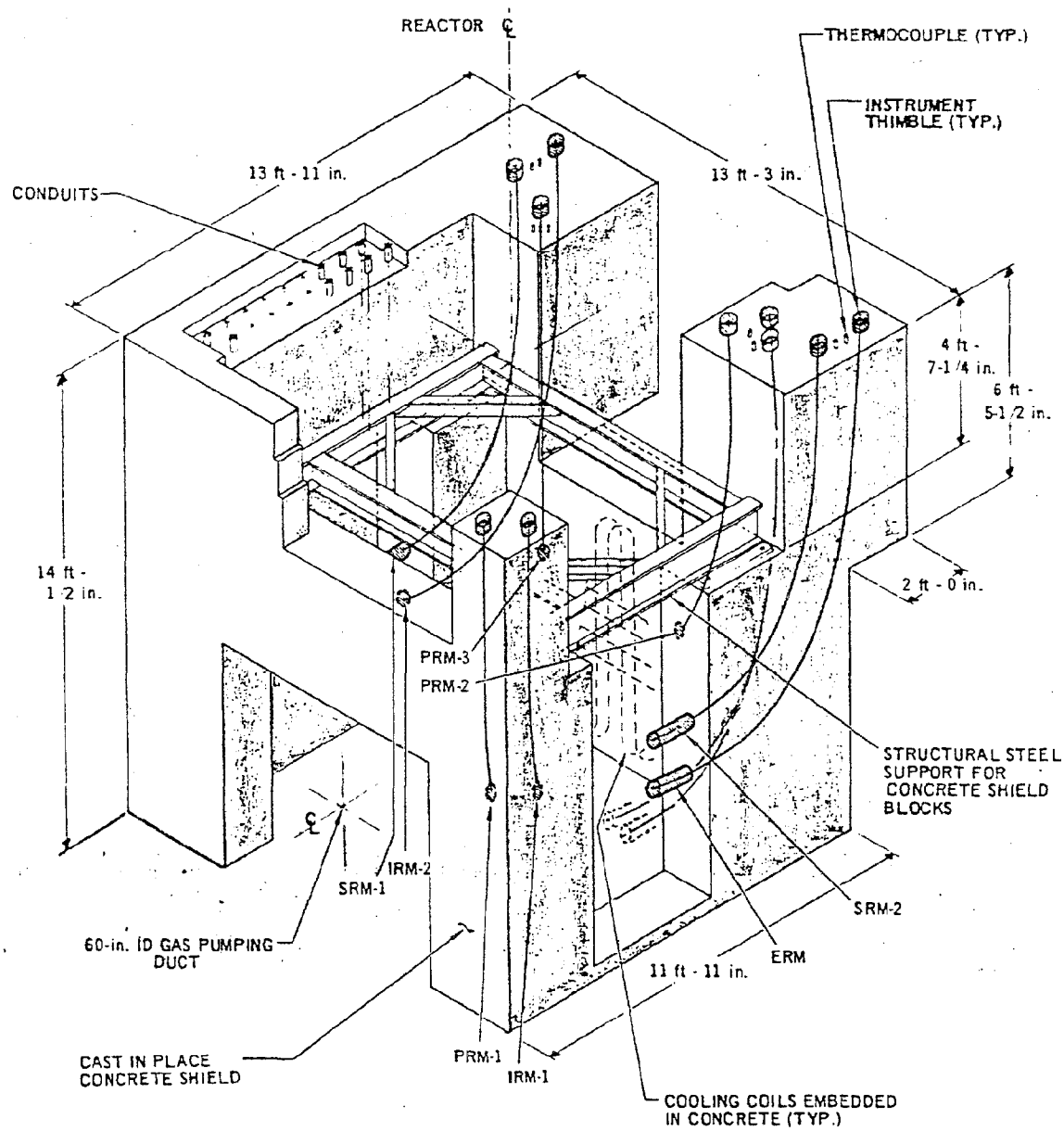

Figure 3. Cast-in-Place Concrete Shield

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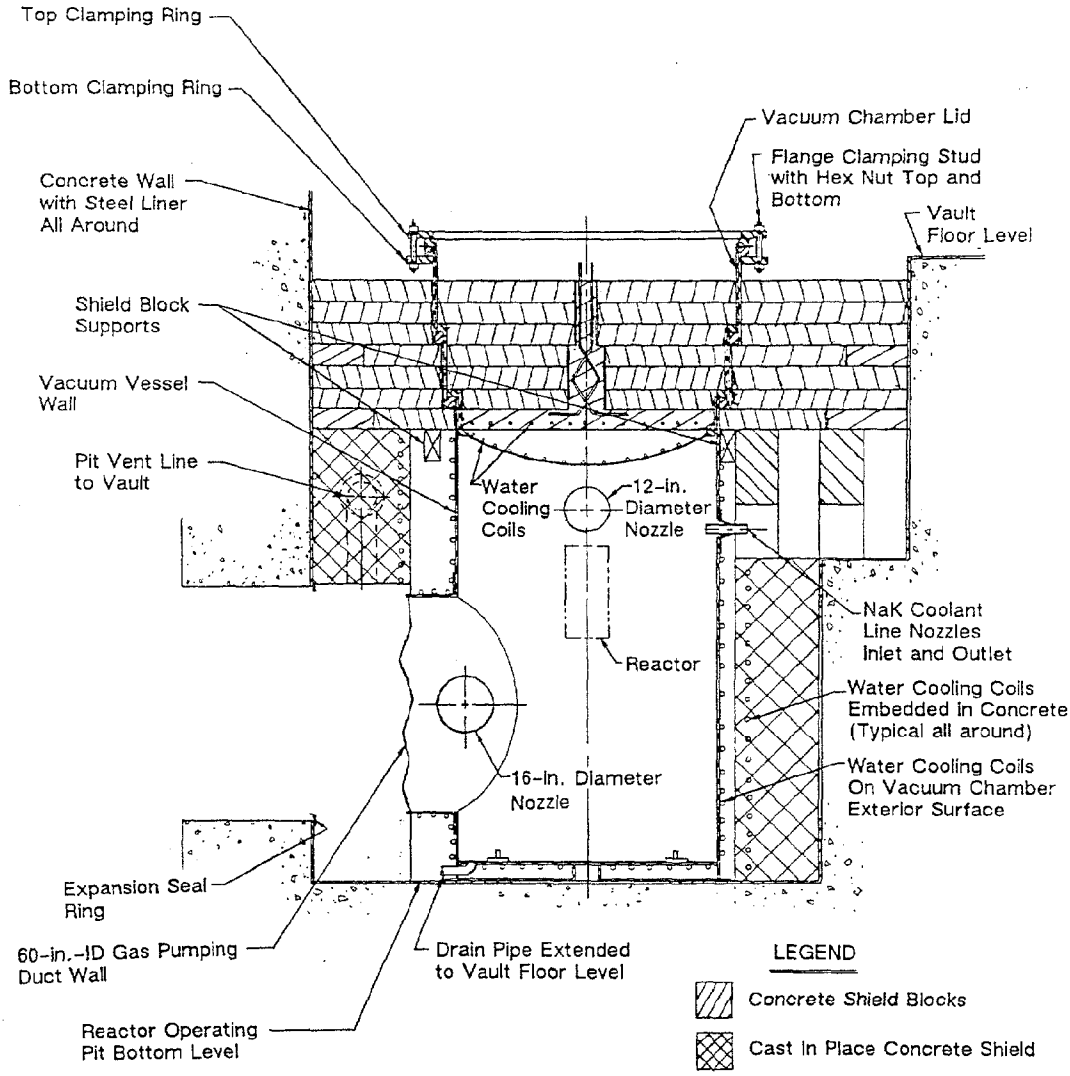
Top Clamping Ring
Bottom Clamping Ring
Concrete Wall with Steel Liner All Around
Shield Block Supports
Vacuum Vessel Wall
Pit Vent Line to Vault
Vacuum Chamber Lid
Flange Clamping Stud with Hex Nut Top and Bottom
Vault Floor Level
Water Cooling Coils
12-in. Diameter Nozzle
Reactor
NaK Coolant Line Nozzles Inlet and Outlet
Water Cooling Coils Embedded in Concrete (Typical all around)
Water Cooling Coils On Vacuum Chamber Exterior Surface
16-In. Diameter Nozzle
Expansion Seal Ring
60-in.-ID Gas Pumping Duct Wall
Drain Pipe Extended to Vault Floor Level
Reactor Operating Pit Bottom Level
LEGEND
Concrete Shield Blocks
Cast In Place Concrete Shield
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Figure 4. Test Cell Elevation Section View Through Vacuum Vessel

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4.0 SHIELD DEMOLITION METHOD SELECTION CRITERIA

There are several concrete demolition methods that are in various stages of development and field application. Initial review of a broad listing gathered from the referenced DOE information center files and in-house surveys shows that for this type of D&D activity no method is ideally or uniquely suited to the Building 059 Shield D&D task. Consequently, the method selection must be made based upon a comparison of each option against a review checklist. (See Table 1.)

The final recommendation and shield removal plan will be based primarily upon ALARA considerations; and then upon staffing requirements; net concrete size reduction-separation-removal rates; capital, operating and maintenance cost estimates; and environmental risk/impact judgments.

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Table 1. Demolition Method Review Checklist
(Sheet 1 of 2)

Primary method:
Additional methods required:

Process

Capability to perform work:
- Remotely
- Horizontally
- Vertically

Rates:
- ft^2 of cut/hr, or
- ft depth of hole/hr, or
- ft^3 of material removal/hr

Limitations/restrictions:
- Space/access required
- Blind or backside work capability
- Limits – depth
  – reach
  – corners

Completeness of separation:
- Primary method
- Secondary method
- Recycle mode

Results

Material form and stability:
Impact of any process overrun:
Secondary results:
- Dust, smoke, aerosols
- Vibration, noise
- Secondary rubble or scrap
- Liquid waste
- Contamination

Handling/removal of material:
- Reduced piece size and weight, minimum/maximum
- Cleanup, manual versus remote

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Table 1. **Demolition Method Review Checklist**
(Sheet 2 of 2)

Safety and Radiation Exposure Potential
- Setup
- Operations
- Maintenance
- Material removal and teardown

Manpower Requirements
- Setup
- Operations
- Maintenance
- Removal and teardown

Equipment and Tooling
- Development/application status
- Adaptability for Building 059 use
- Ruggedness – dependability
- Maintenance/repair ease
- Utilities and consumables required
- Secondary (follow-up) process requirements

Costs
- Equipment and tooling
- Supplies and consumables
- Operations
  - Setup and checkout
  - Demolition
  - Maintenance
- Waste disposal

  (Postdemolition shield disposal not included as that disposal is assumed equal for all cases)

Schedule
- Setup and preparation
- D&D
- Removal, teardown, and cleanup

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5.0 CONCRETE SHIELD REMOVAL OPTIONS

The option list itself is not a simple single entry listing. For example, Rock Splitting, Expansive Compound, and Wire Cutting demolition all require some degree of initial hole drilling to get started. Also Circular Sawing and Core Stitch Drilling both require use of supplemental methods to complete the separation and size reduction portions of the task. However, for purposes of classification for this study, it was decided to lump the methods according to the major demolition technique employed. With this approach it was possible to narrow the initial list down to the 10 options (major methods) shown in Table 2 for the Building 059 Cast-in-Place High Density Concrete Shield D&D.

Table 2. Demolition/Removal Options

1)	Abrasive Water Jet
2)	Breaker Ram
3)	Circular Sawing
4)	Controlled Blasting
5)	Core Drilling
6)	Demolition/Expansive Compounds
7)	Flame Cutting
8)	Laser Cutting
9)	Rock Splitter
10)	Wire Cutting

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The following methods were eliminated from further consideration, primarily for the reasons listed below:

<u>Chipping Hammer (Spall), Explosive Cutting, Grinding, and Paving Breaker</u>

These methods were deleted as too limited in capability and therefore not feasible or appropriate for the heavy reinforcement and massive structure of the Building 059 shield. This conclusion concurs with the information presented in Reference 4, (DOE/EV/10128-1) Decommissioning Handbook, Table 7.1.

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Wrecking Ball/Slab

Deleted because of the confined space of the Building 059 test cell and vault working areas. This confinement will not provide sufficient swing or drop heights for this method to be successful. Furthermore, the resultant effect of the ball impact shock and vibration upon the building foundation and the adjacent groundwater table flow paths presents an unjustifiable risk to the environment.

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6.0 DISCUSSION

Almost every large nuclear decommissioning project has had to contend with the cutting and demolishing of concrete structures such as:

- Heavily reinforced concrete used to construct reactor biological shields, the walls of hot cells, and building foundations and walls.
- Massive heavy concrete (with metal or magnetite aggregate), with little or no added reinforcement, used for certain biological shields.
- Prestressed reactor vessels and reactor buildings.
- Standard lightly reinforced or nonreinforced concrete building structures.

Demolition of such concrete structures is not unique to nuclear installations and many of the successful nuclear plant techniques are modified versions of those used in the nonnuclear industries. However, such demolition is still a difficult and time consuming task because of the reinforcing material and the volume of concrete. The nuclear industry has the additional problems of concrete density and radioactive contamination, which often require remote operation of the demolition equipment. The ten primary cutting and demolition techniques that upon initial review were judged suitable for evaluation for this shield removal task were listed in Table 2 and are described in more detail in this section. Potential shortcomings and problem areas relative to a method's application to the Building 059 shield D&D task are discussed in Section 7.0.

6.1 Abrasive Water Jet

In the abrasive water jet process, a small diameter, high velocity water jet and a stream of solid abrasives are introduced into a specially shaped abrasive jet nozzle from separate feedports (see Figure 5). Here part of the water jet's momentum is transferred to the abrasives, whose velocity rapidly increases. One abrasive water jet tool uses water at 6,900 psi and a sapphire nozzle to form the coherent high velocity jet.

A deep kerf tool has been developed to cut concrete up to 5 ft thick from one side using a rotary nozzle that makes a slot in the concrete wide enough to accommo-

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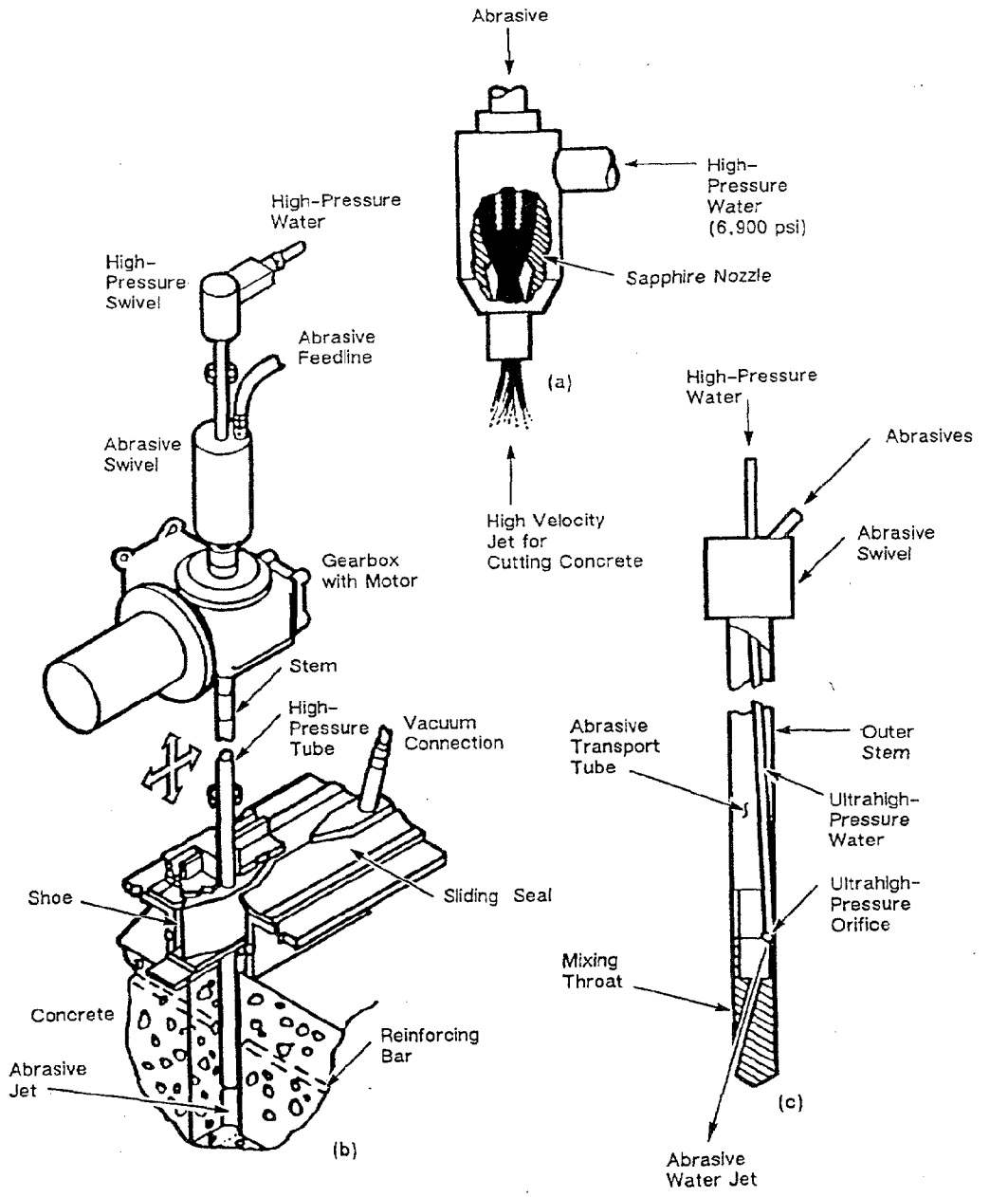

Figure 5. Abrasive Water Jet Cutting Tools. (a) Sapphire Nozzle Mixing/Accelerating Chamber Schematic, (b) Deep Kerf Abrasive Water Jet Tool, and (c) Its Nozzle

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date the cutting tool as it advances. A shroud and vacuum system is used to contain the wastes with a claimed recovery efficiency of over 99%. Garnet sand is the abrasive most commonly used for cutting; however, steel grit is also being investigated because it can be separated magnetically and then reused.

In Japan, an abrasive water jet system has been developed for use, along with other techniques, in the dismantling of the biological shield walls of the Japan Power Demonstration Reactor.

In the United Kingdom, a device using high-pressure water at up to 1,450 psi and entraining crushed copper slag as the abrasive is being developed to cut reinforced concrete. This abrasive water jet has been used to cut through a concrete test block containing seven steel reinforcing bars 1.63 in. in diameter at 3.54-in. centers. However, the application of this technique for dismantling large reinforced concrete reactor structures will be limited because the process results in large volumes of dirty and contaminated water and is relatively slow.

6.2 Breaker Ram

Breaker Rams are often used for demolishing concrete structures less than 2-ft thick with light reinforcement. The equipment consists of an air operated or hydraulically operated impact ram with chisel points mounted on a backhoe arm. The equipment should be used in conjunction with a fine spray of water to minimize dust; however, the spray should be synchronized with the ram head to avoid excessive use of water. With the ram head mounted on a backhoe, the operator has approximately a 23-ft reach and the ability to position the ram in limited access structures.

A powerful hydraulic hammer mounted on an electrohydraulically powered, remotely controlled "Mini-Max" machine (Figure 6) was used to dismantle the concrete biological shield and other concrete during the decommissioning of the R-1 research reactor in Stockholm (Reference 5). Similar backhoe mounted equipment was used to dismantle the Rockwell Sodium Reactor Experiment (SRE) (Reference 6) and Shield Test Irradiation Reactor (STIR) facilities (Reference 7).

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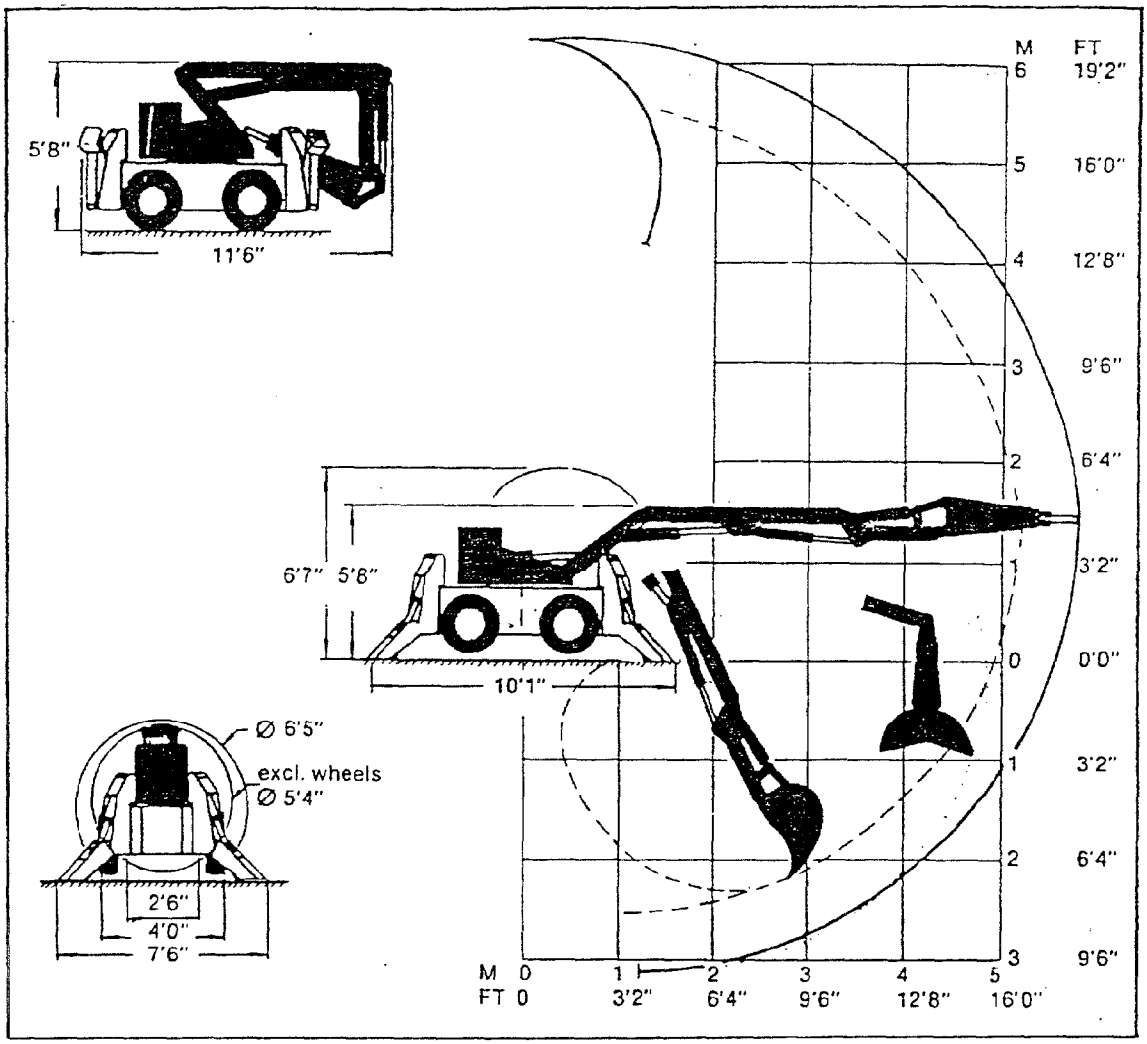

Technical Data

Motor output—22 kW, 440-480 V, 50 A and 60 Hz
Total weight with breaker tool 7200 lb.

Figure 6. Mini-Max Operating Specifications

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An alternative attachment to the hydraulic hammer for some demolition tasks may be the mobile shear or concrete pulverizer such as that made by LaBounty Manufacturing, Inc., of Two Harbors, Minnesota. These shears can be pin mounted on an excavator stick arm or attached through a 360-deg rotating turntable to the boom arm end. Depending upon the unit size, reach, jaw opening, cutting knife configuration, and replaceable tip shape selected, concrete sections up to 4-ft thick with rebar and embedments up to as large as 18-in. H beams can be cut up and demolished. The shear force capability ranges from 31 tons at the tip to 140 tons at the throat for the smallest units and can go to over a 1,000 tons for the larger units.

The major applications problems to be solved for the Building 059 shield removal task are equipment access, mounting, and the method of making the initial concrete bites.

6.3 Circular Saws, Diamond or Carbide Tipped

Large diamond or carbide tipped saws have been developed for cutting thick concrete walls (Figure 7) and floors (Figure 8). This technique is generally used when disturbance to the surrounding material must be kept to a minimum. These saws can cut through reinforcing rods, although the rods tend to break off diamonds from the blade, causing blade wear, replacement expense, and lost time for blade changes. The blade is rotated by an air, electric or hydraulic motor. For most applications the saw will be mounted on a guide that also supports the saw's weight. The dust produced by the abrasive cutting is controlled by using a water spray, which, for nuclear applications, must be contained to prevent the spread of contamination. The abrasive blade produces no vibration, shock, smoke, sparks or slag and is relatively quiet.

Thicknesses of up to 3 ft have been cut with concrete saws. The maximum cut thickness is equal to approximately 1/3 of the blade diameter. The saw cuts approximately 150 in^2/min. of cut surface regardless of the length or thickness (depth) of the cut. Cutting can be done either manually or remotely, depending on the size of the saw and the work area location and environment.

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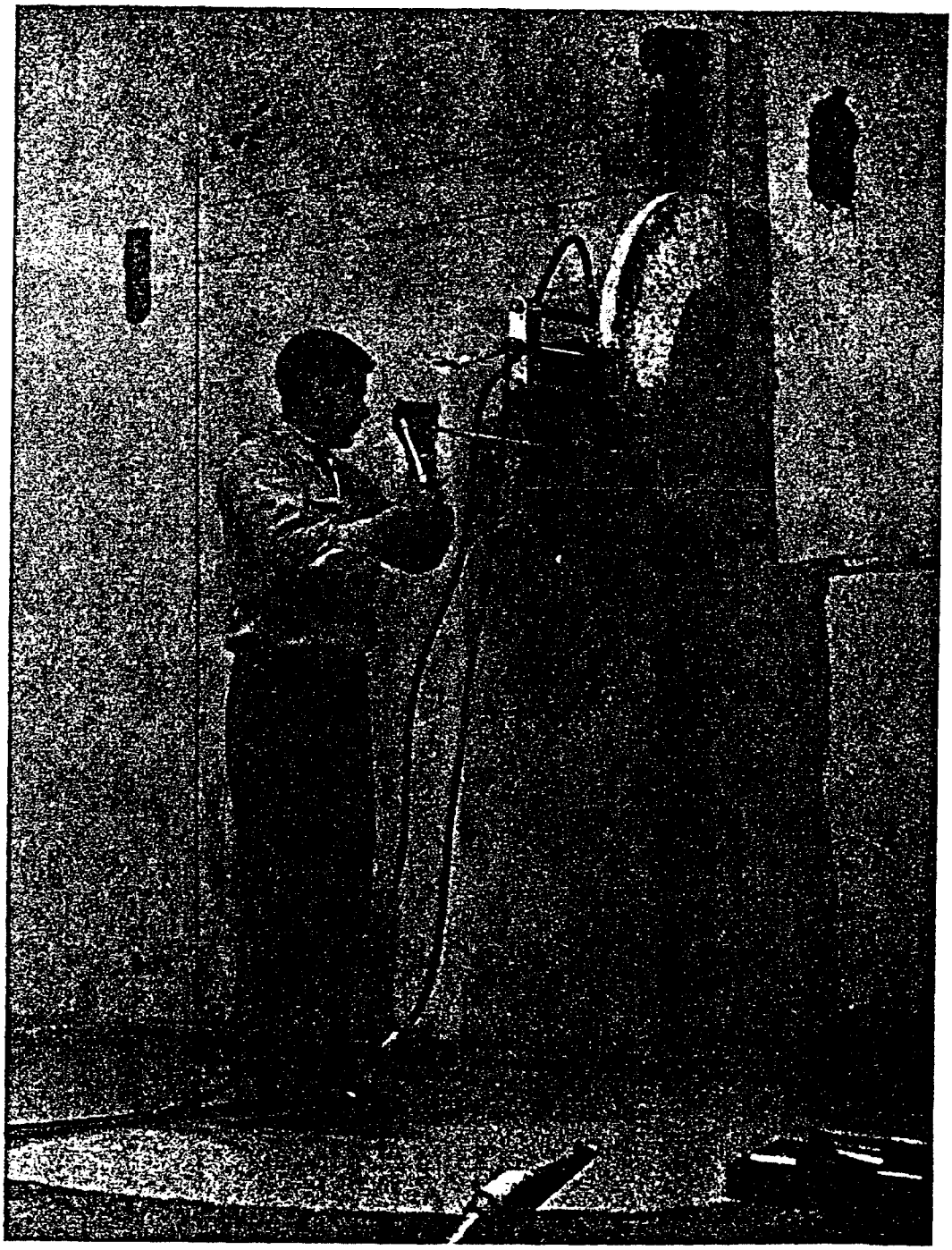

Figure 7. Wall Saw

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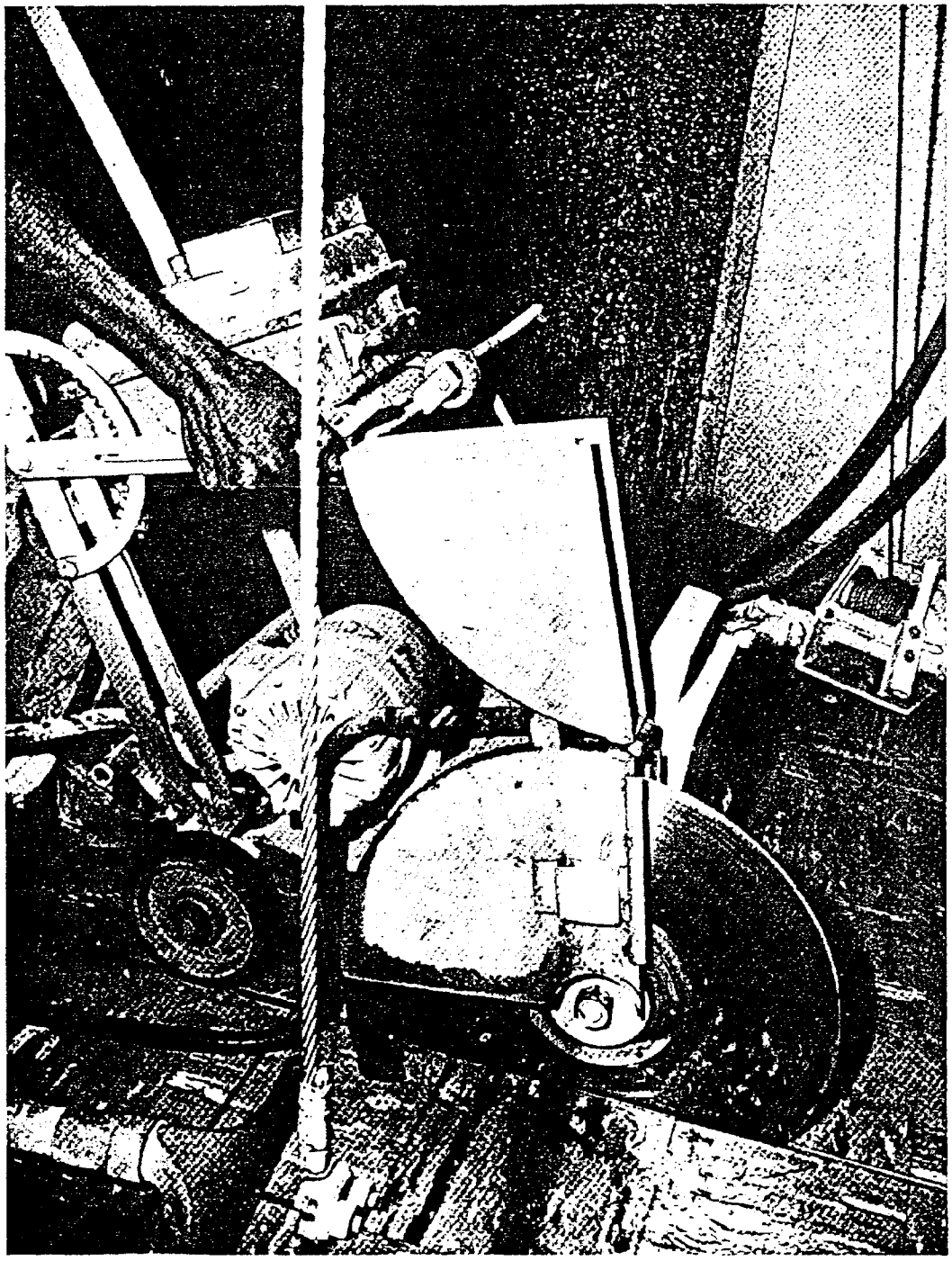

Figure 8. Floor Saw

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The choice of material for the saw tip and of the binding agent is strongly influenced by the type of aggregate in the concrete. Specific tests are usually required for each new application.

Overcutting or back edge and corner cut completion may be a problem for some locations. Alternate methods such as drilling and rock splitting may be required to complete separation. Figure 9 illustrates the application of backside core drilling to complete a large concrete separation.

6.4 Controlled Blasting

Controlled blasting is often recommended for demolition of massive, heavily reinforced concrete sections. The process consists of: evaluating the concrete structure, aggregate, and possible explosive combinations; drilling tailored blast holes in the concrete; loading them with explosive charges; and detonating the charges using a 1 to 3 millisecond delayed firing technique. The delayed firing increases fragmentation and controls the direction of material movement. Delayed firing also reduces the vibration impact on adjacent rock, soil, and structures. Each borehole fractures radially during the detonation. The radial fractures in adjacent boreholes combine to form a fracture plane. The detonation wave separates the fractured surfaces and moves the material toward the structure's free face. Figure 10 illustrates a typical blasting round for demolition of massive concrete and explains the terminology used in designing a blast (e.g., the burden is the distance from the free face). The following are typical standard blasting ratios:

(3) – Burden: 20 to 40 times the diameter of the explosive;

(5–7) – Hole depth: 1.5 to 4 times the burden;

(7) – Subdrilling: a minimum of 0.3 times the burden;

(6) – Stemming: 0.5 to 1 times the burden;

(4) – Spacing: 1 to 2 times the burden.

The most versatile tool for preparing blast holes is a percussion drill which can economically drill 1– to 2–in.–diameter holes in concrete over a wide hardness range.

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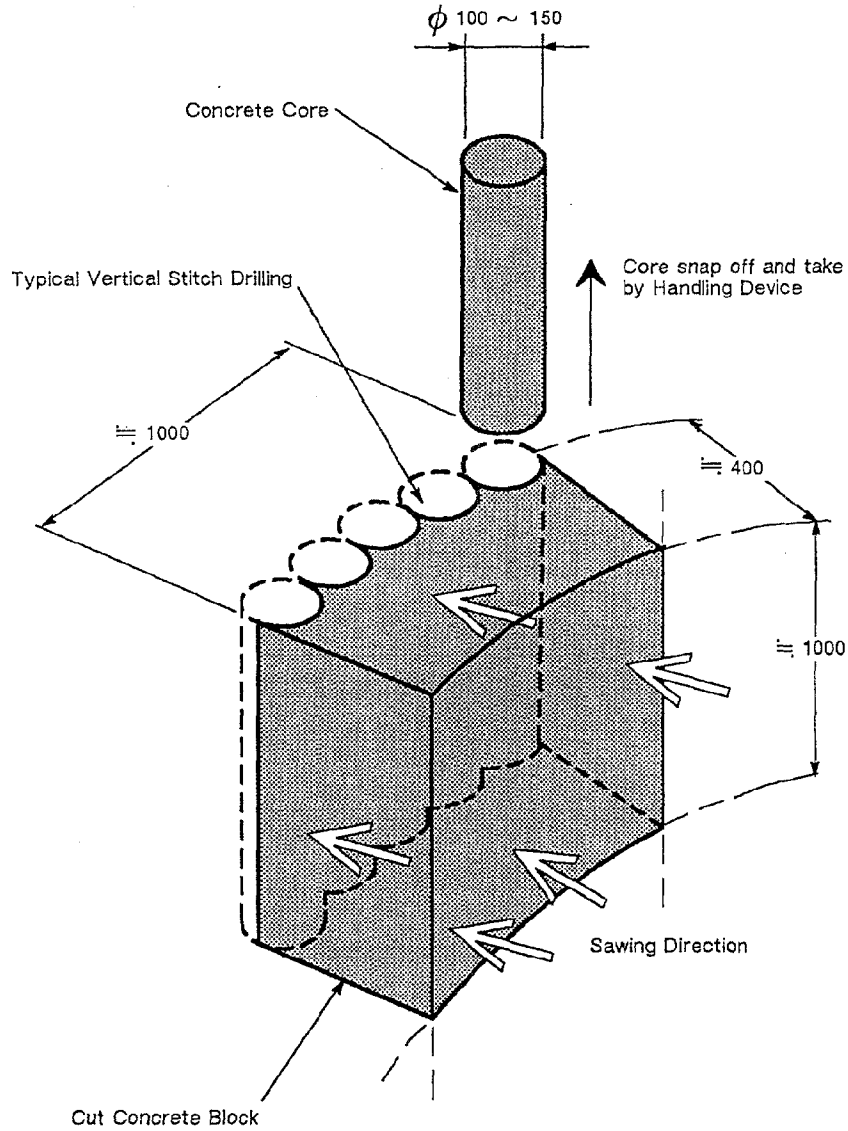

Figure 9. Large Cut Concrete Block Schematic

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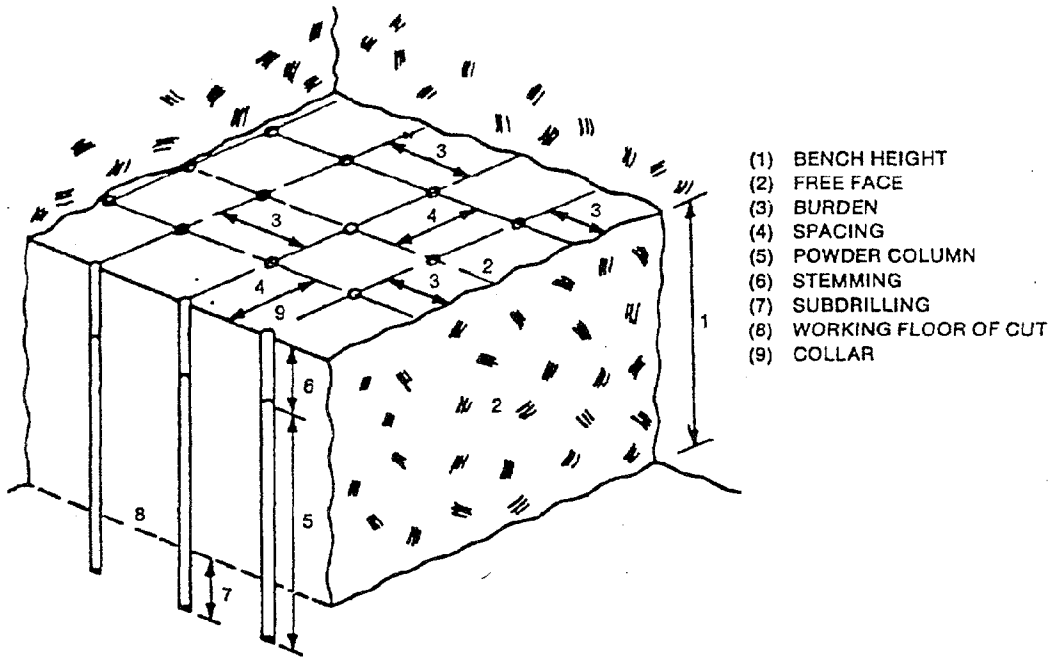

Figure 10. Blasting Round Schematic

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Typical percussion drilling equipment can drill a 6- to 7-ft long hole in 3 to 4 min. in standard concrete. Other types of drilling methods include electric, pneumatic and diesel driven rotary drills and diamond core abrasive drills. The diamond core abrasive bits are more expensive than percussion drills but bit life is longer. However, abrasive drilling is slower than percussion drilling for cutting through reinforcing bars.

The selection of the best type of explosive requires an evaluation of the properties of both the explosive and the concrete. A blasting expert should be employed to select the best explosive for the purpose. Typical types of explosives used for concrete removal include: PETN (pentaerythritol tetranitrate), 85% high velocity gelatin dynamite, cast TNT (high detonation pressure primers), and water gel explosives.

A blasting mat (composed, for example, of automobile tire sidewalls tied together) should be placed over the blast area. Continuous fog sprays of water should be used before, during, and after the blast to hold down dust. The exposed reinforcing bars may then be cut, completing the demolition.

6.5 Core Drilling

This general category of concrete removal is divided into two subdivisions as discussed below. Basically the drilling technique is the same for both, the difference being in the size, shape, and location of material removed. In either case, complete removal of an entire concrete structure, especially one with reinforcing and attachments or embedments, usually requires the use of other supplemental removal methods. As with sawing, water is used to control the abrasion dust and must be contained for contamination control in nuclear applications.

6.5.1 Core Stitch Drilling

Core stitch drilling is recommended for nonreinforced concrete, especially when the surroundings are not to be disturbed. The technique consists of close pitched drilling of holes through the concrete using a diamond or carbide tipped drill bit in an electric or fluid driven rotary drill. The center lines of the holes are located along a path corresponding to a desired breaking plane in the concrete. The hole pitch is such that there is very little concrete left between the adjoining holes (less than half the ra-

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dius of the holes). When a line of holes has been drilled along the breaking plane, bars or rock splitters are inserted into the holes and force is applied in a line perpendicular to the breaking plane to shear the remaining concrete.

A variation of this method reduces the hole pitch spacing until the holes intersect and no additional force is required to separate the concrete (see Figure 9).

This is a fairly slow process and for reinforced and high density concrete structures the removal rate is drastically reduced, but could be improved by the use of multiple drilling heads.

6.5.2 Large Core Drilling

Core drilling can be used to remove cylindrical sections from all types of concrete. The drill consists of a hollow cylindrical pipe with a water cooled, diamond tipped cutting edge. Cylindrical blocks up to 3 ft in diameter have been sectioned with this process. Also, the blocks can be sized to fit into a 55-gal drum for disposal. Here again, reinforcing, embedments, attachments and the concrete density all strongly influence the achievable drilling rate and thus the corresponding concrete removal rate.

6.6 Demolition/Expansive Compounds

Demolition/expansive compounds are only effective with nonreinforced or lightly reinforced concrete. The proprietary compounds consist of limestone, a siliceous material, gypsum and slag. The powder is mixed with water and then packed into holes drilled into the concrete on a fracture line of predetermined burden, spacing and depth (see Figure 11). No hole caps are required if the hole depth is at least six times the hole diameter. Pressure will develop to over 4,200 psi, well over the tensile strength of ordinary concrete, within 20 hr.

Cracks will form and propagate along the fracture line. The fractured burden may then be removed with a pavement breaker, backhoe or bucket loader, but reinforcing rods must usually be cut separately. Expansive compound demolition tests have been conducted at Santa Susana on two 25-yr-old solid reinforced concrete structures as reported in Reference 8. The expansion compound is not classified as a hazardous substance and can easily be stored and handled. There is no noise or vibration (except for

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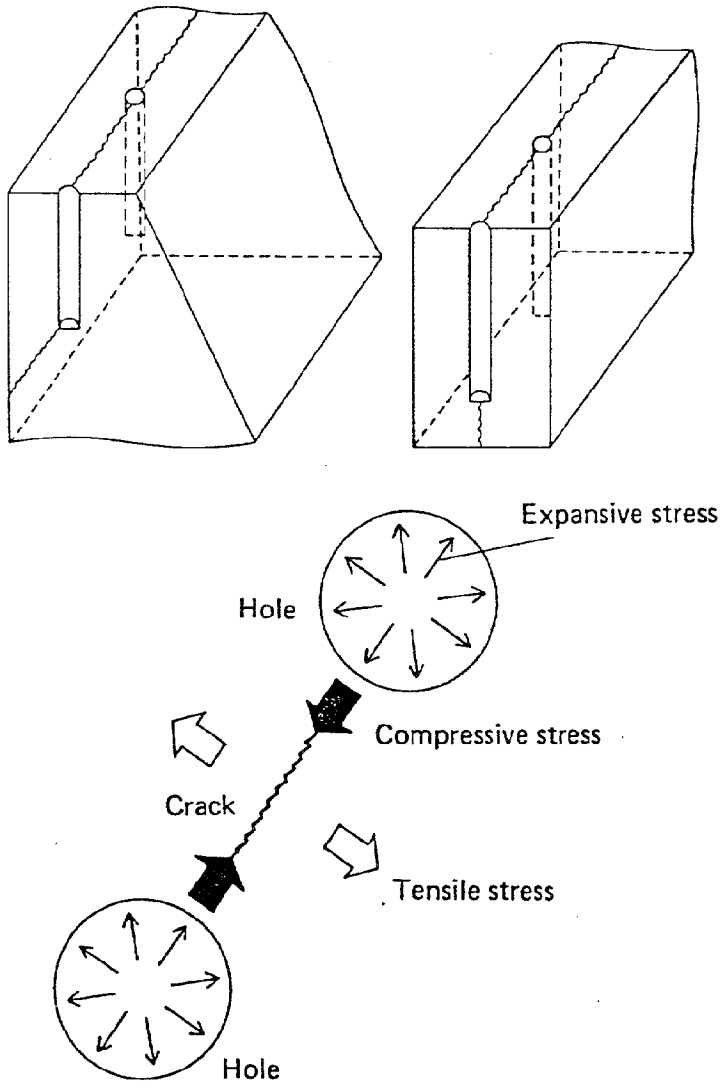

Figure 11. Demolition/Expansive Compound Fracture Mechanism Schematic

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drilling holes), or flyrock or gas release; but contamination containment and dust control are required during drilling and removal operations.

The hole patterns and sizes required will be similar and the net demolition rate will also be about the same as for the rock splitter case (i.e., less than 2 yd^3/day).

6.7 Flame Cutting

Flame cutting can be used when vibration of the adjacent area is not allowable and the concrete is thicker than can be cut using other methods, such as a diamond saw blade. Flame cutting of concrete uses of a thermite reaction process whereby a powdered mixture of iron and aluminum oxidizes in a pure oxygen jet. The temperature in the jet is in the range of 2000 to 5000 °C, causing rapid decomposition of the concrete in contact with the jet. The mass flow rate through the flame cutting nozzle clears away the decomposed concrete and leaves a clean kerf. Flame cutters can cut through concrete with or without reinforcing. However, added iron in the concrete, such as rebar or other embedments, sustain the flame and augment the reaction.

To start, a hole is drilled through the slab to prevent torch damage from blowback of material. The torch is then moved along the workface by the operator using a variable speed electric motor mounted on a metal frame that covers the area to be cut, but it is a slow process covering about 1 ft^2 of cut per hour.

During flame cutting, very large amounts of dust, smoke and heat are produced. In confined areas, these must be removed using augmented exhaust systems that include flexible ducts, prefilters and, if the material is activated, high-efficiency particulate air (HEPA) filters. Moreover, the effluent gas must be cooled to prevent damage to the HEPA filters, and the filter systems must be designed so that the prefilters can be changed easily.

Another type of flame cutting is the thermite reaction lance. This method can cut almost any material encountered in a nuclear facility and is suitable for irregular surfaces. This equipment consists of a combination of steel, aluminum and magnesium wires packed inside an iron pipe through which a flow of oxygen gas is maintained. Typical lances are 8 to 10 ft in length and 1.5 to 2.5 in. in diameter. The lance is

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ignited in air by a high temperature source such as an electric arc or an oxygen burning torch. During operation, the thermite reaction at the tip completely consumes the constituents of the lance and causes the temperature to reach 3900 to 9000°F. For metal cutting the procedure has been reported as generating an approximately 1-in.-diameter hole at the rate of 1-ft depth per minute, provided that the molten metal is free to flow away from the kerf. A 10-ft lance will burn for about 6 min.

During cutting, the lance must be hand held and the operator must be equipped with fireproof protective clothing and a mask. The smoke and dust problems with this equipment are similar to those experienced with flame cutting. Because the process generates considerable smoke, a control envelope and ventilation must be provided, particularly if the component being cut is radioactive.

Work sponsored by the Commission of the European Communities (CEC) in Italy shows that in a specific case 50% more man-hours were required to dismantle reinforced concrete structures using a thermal lance than using blasting techniques. However, lance cutting causes less damage to secondary structures.

6.8 Laser Cutting

Laser cutting is suitable for all metal and concrete structures. A high power gas laser generates infrared radiation that can be focused using water cooled reflecting optics to produce power densities capable of cutting steel or concrete. However, the cutting can be carried out only in air because water would excessively diffuse the laser beam. The laser gas can be inert (CO_2, He, N_2) or reactive (O_2, air). For example, a CO_2 laser uses an inert gas as the lasing medium, with a typical gas composition of about 78% He, 18% N_2 and 4% CO_2. The laser beam melts and vaporizes the material being cut and removes it from the cutting area by means of a high velocity gas jet. Lasers in the range of 1 to 15 kW can be used to cut concrete or steel.

A CO_2 laser cutting system consists of a laser beam generator and associated controls, high voltage and gas supplies, beam handling and focusing optics, a cooling system and a nozzle assembly.

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High power laser cutting systems tend to be relatively expensive and require large spaces; however, it may be possible to mount such systems on skids or trailers and to direct the laser beam with mirrors and focusing lenses to bring the beam to the piece being cut instead of moving the laser source for each cut.

In Italy, a program sponsored by the CEC was undertaken to develop laser technology for the dismantling of concrete structures and metal components. The objectives were to develop techniques for cutting reinforced concrete, drilling holes in concrete for the placing of explosive charges, and cutting thin and medium thick metal components. Preliminary results show that it was easier to cut steel reinforced concrete than nonreinforced concrete. The laser cutting of concrete posed no problem except for high dust production and the added smoke and aerosols produced with reinforced structures. All of these by-products tend to reduce laser efficiency. The drilling of holes in concrete also proved possible, but the initial holes were too small for inserting explosive charges for dismantling, and hole enlargement took considerable time.

Although progress has been made in using laser technology to assist in decommissioning, it is still a fact that capital equipment costs are very high and much more work is required before it will become a viable option for cutting or drilling massive concrete.

6.9 Rock Splitter

The rock splitter is ideal for fracturing concrete in limited access areas where large breaker rams cannot operate. The process is relatively quiet except for the hole drilling, and is used extensively for demolition near hospitals and in densely populated areas.

The rock splitter fractures concrete by hydraulically expanding a wedge into a predrilled hole until tensile stresses are great enough to cause fracture. For long sections of concrete, multiple splitters are used along the desired fracture line. The tool consists of a hydraulic cylinder that drives a wedge shaped plug between two expandable guides (called feathers) inserted in the predrilled holes (Figure 12). The rock splitter unit is powered by a hydraulic supply system and typically operates at greater than

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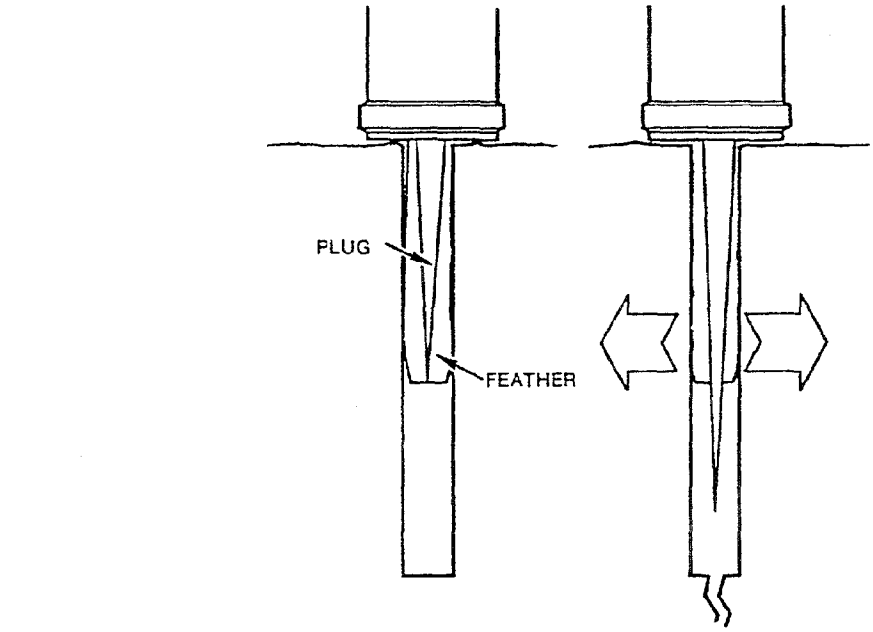

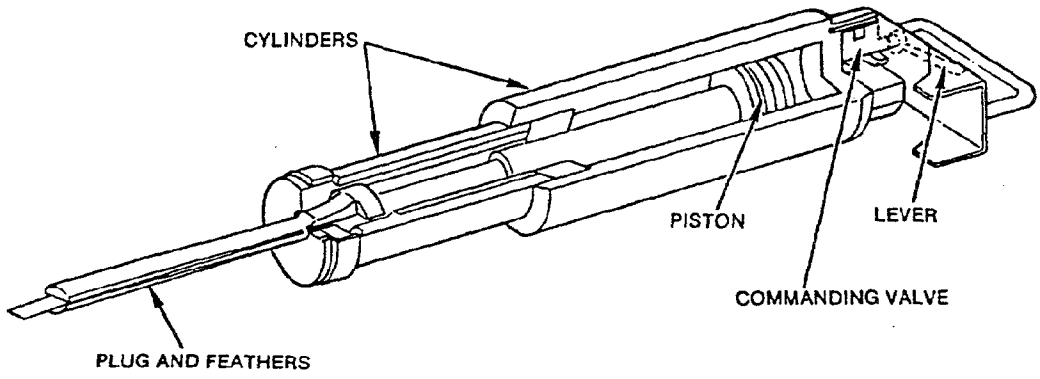

Figure 12. Schematic of Rock Splitter

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7,000 psi pressure. The hydraulic unit may be powered by air pressure, gasoline engine, or electric motor sources.

Units are available to develop splitting forces approaching 350 tons. The maximum lateral expansion of the feathers is approximately 0.75 in. The concrete may then be separated at a fracture line using a backhoe mounted ram or similar equipment. However, the reinforcing rod in reinforced concrete must be cut before full separation is possible. Additional holes and fractures will be necessary to expose the reinforcing rod for heavily reinforced concrete.

Removal rates up to about 250 yd3/day for nonradioactive, nonreinforced concrete have been achieved. For the added effort required with reinforcing and the added restrictions imposed by radioactive environments, less than 2 yd3/day will probably be realized.

6.10 Wire Cutting

A process using diamond wire (Figure 13) to cut massive blocks of reinforced concrete has been developed and is being used at nuclear power plants and other facilities. To make such a cut, holes are drilled through the structure at the four corners of the block to be removed. The diamond wire is fed down through one hole and back out an adjoining hole, joined together to make a loop, and then tensioned and pulled to make the cut (see Figure 14). The cutting speed is about 20 ft2/hr. This process is fairly well developed and has been used in nonnuclear applications for some time.

The advantages of this process include the capability to make precise cuts, a very low amount of debris created, relatively high cutting speeds, relatively low noise and vibration, and the capability to control block size. Also, the amounts of water required for cooling and dust control are relatively small and the water can be recycled.

In Switzerland, a plain wire saw using either silicon carbide or Carborundum powder in a suspension as the cutting material was tested for cutting reinforced concrete blocks. The test results indicate that reinforced concrete blocks can be size reduced at a very low cost. In situ concrete removal rates and costs will be affected by the complexities of the hole drilling, trolley placement and wire loop feed, the wire life

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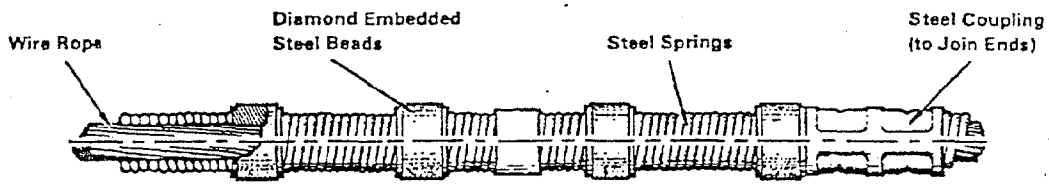

Figure 13. Diamond Wire Assembly

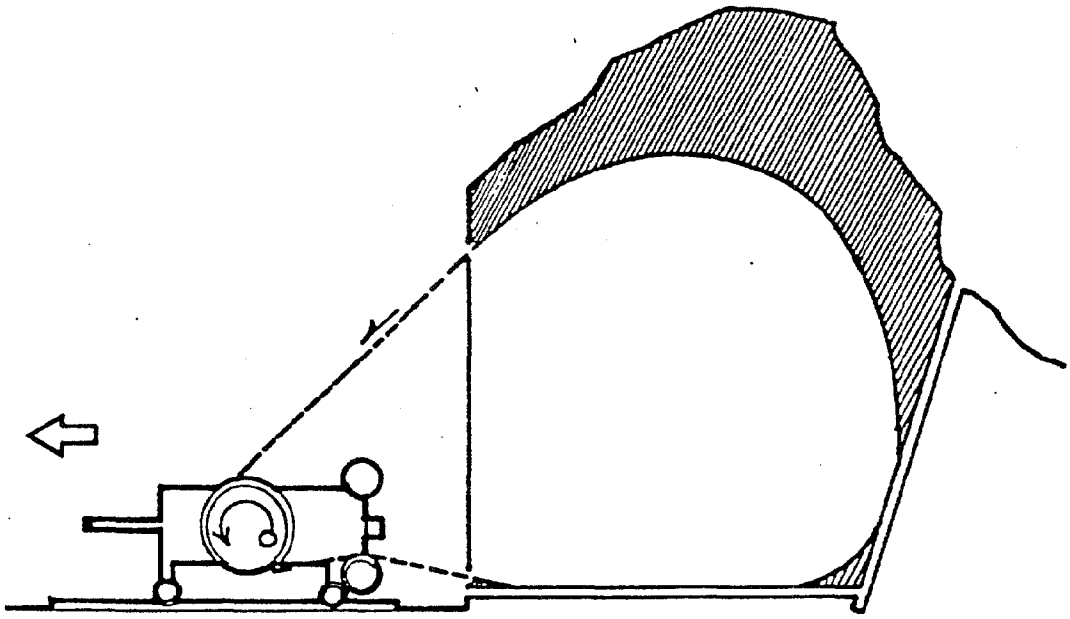

Figure 14. Typical Wire Cutting Arrangement

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realized, and the efficiency restrictions imposed by the radiation environment. However, with this technique, remotely controlled cutting can continue around the clock once a wire loop has been set up.

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7.0 ELIMINATION OF CANDIDATE OPTIONS

A second round review of the ten concrete cutting and removal methods described above revealed that on a relative evaluation scale, five of the techniques do not measure up for this specific application. Each of these methods, with its relative shortcomings, is listed below. Because five other options still remain, these five less attractive techniques were dropped from further consideration, regardless of their individual ranking position in the cost, schedule and man–hour categories. The methods eliminated are:

No. 1 Abrasive Water Jet,

Dropped because of the low cutting rate reported (less than 5 ft^2/hr) and the high abrasive water usage rate (greater than 3 gal/min.), which, even with recirculation, leads to a potential contamination control problem and certain added radioactive waste disposal cost. Also, the section thickness for many of the required cuts would be at the upper limits of the current technology and equipment capability.

No. 4 Controlled Blasting

This method showed a low relative cost, a short schedule for a normal 5–day/1–shift workweek, and close to the lowest radiation exposure potential. However, there are considerations for this case that cannot be readily quantified at this time, which must be addressed before the method can be selected. These include shock to the building structure and surrounding rock and subsoil, confinement of the dust and all radioactive material, assurance of a watertight envelope and ground water leakage control, and the probability of a more lengthy and difficult management and agency approval cycle. In view of the above unknowns, it is recommended that this method not be considered further for this application.

No. 5 Core Drilling

Dropped because of the extremely low test core drilling rate that has been realized in the Building 059 high density heavily reinforced concrete and because of the large number of holes that would be required. A ratio of greater than 6 to 1 compared with even the rock splitter case was estimated for the stitch drilling case. In addition,

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supplemental removal methods are still required to complete the demolition task, especially if large core drilling is the primary method selected.

No. 7 Flame Cutting

Dropped because of the very confined working area, the status of the ventilation equipment in Building 059, and the radioactivity level of the shield structure to be demolished. The extremely large smoke, dust, aerosol, and heat loads that would be generated by this method would require excessive investment in new cooler, filter, confinement, and ventilation equipment. Most of this equipment would become radioactively contaminated during the demolition, and thus, would require additional time and money for its decontamination or disposal as additional radioactively contaminated waste material at the end of the task.

No. 8 Laser Cutting

Dropped because of its high initial capital investment requirement and its present state of development. The setup and focusing of the laser beam path to cut exactly where required would be difficult currently in the Building 059 environment. Also, as with flame cutting, there would be a smoke, dust and aerosol handling problem, which would seriously decrease the laser cutting efficiency.

The five remaining candidate concrete removal methods are:

- Breaker Ram
- Circular Sawing
- Expansive Compound
- Rock Splitter
- Wire Cutting.

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8.0 EQUIPMENT AND MATERIAL REQUIREMENTS

There is considerable material and equipment that will be required for this shield removal task regardless of which demolition method is finally selected. Such things as protective clothing, waste shipping boxes, conventional tools, plastic, torches, cutters, etc., will be common necessities for all methods.

The significant cost items will be the equipment, fixtures, tools and consumables associated with each of the major methods considered. In addition, metal cutting equipment is required both for some of the preliminary setup and preparation steps, and for some final rebar and embedment separation and size reduction for removal. Much of this metal cutting equipment, as well as the waste material moving equipment, will already be on hand following the vessel cutup and removal tasks, and therefore will not be reestimated here.

Rough order of magnitude (ROM) identification and estimates of the other equipment and material needs are summarized in Table 3.

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Table 3. Equipment and Material Estimates (Sheet 1 of 2)

Primary Method	Secondary Follow-up Method	Equipment Items	ROM $ ($000)	Material Items	ROM $ ($000)
Abrasive water jet	–	Pump, jets (2)	125.0	Abrasive	5.0
		Fixtures and guides	10.0	Spare parts and guides	15.0
		Recirculation equipment	5.0		
		Total	140.0	Total	20.0
Breaker ram	Rebar cutter	Breaker and mount	125.0	Moil Points	15.0
		Torch and cutter	*	Breaker and spare parts	40.0
				Torch gas and spare parts	5.0
		Total	125.0	Total	60.0
Circular saw	Drill, splitter, or breaker and rebar cutter	Saws	36.0	Drill bits	5.0
		Drive and guides	5.0	Moil points	5.0
		Drill	15.0	Torch gas and spare parts	5.0
		Splitters or breaker	25.0		
		Torch and cutter	*		
		Total	81.0	Total	15.0
Controlled blasting	Breaker and rebar cutter	Drills	25.0	Drill bits	15.0
		Blasting equipment	17.0	Explosives and primers	5.0
		Breaker hammers	25.0	Moil points	2.0
		Torch and cutter	*	Torch gas and spare parts	3.0
		Total	67.0	Total	25.0
Core drilling	Drill, splitter, breaker, and rebar cutter	Drills (4)	45.0	Drill bits	20.0
		Splitters (2)	20.0	Moil points	5.0
		Breaker	25.0	Torch gas and spare parts	
		Torch and cutter	*		
		Total	90.0		30.0
Expansive compound	Breaker and rebar cutter	Drills	15.0	Drill bits	5.0
		Breaker	25.0	Moil points	5.0
		Torch and cutter	*	Torch gas and spare parts	5.0
				Expansive compound and mixing/pouring equipment	2.0
		Total	40.0	Total	17.0

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Table 3. Equipment and Material Estimates
(Sheet 2 of 2)

Primary Method	Secondary Follow-up Method	Equipment Items	ROM $ ($000)	Material Items	ROM $ ($000)
Flame cut	–	Filter, ventilation, and cooler equipment estimate	45.0	Flame cutter	12.5
				Thermite fuel	10.0
				Torch gases	10.0
				Lances	5.0
		Total	45.0	Total	37.5
Laser cut	Rebar cutter (backup)	Power supply and beam equipment	70.0	Laser gases and parts	50.0
		Filters, etc.	30.0	Torch gases and spare parts	10.0
		Torch and cutter	*		
		Total	100.0	Total	60.0
Rock splitter	Breaker and rebar cutter	Drills	15.0	Drill bits	5.0
		Splitters (3)	45.0	Moil points	5.0
		Breaker	25.0	Torch gas and spare parts	5.0
		Torch and cutter	*		
		Total	85.0	Total	15.0
Wire cutter	Drill, splitter, and rebar cutter	Drill	15.0	Drills	15.0
		Pulleys, trolley, drive and tensioner	30.0	Wire	15.0
				Torch gas and spare parts	10.0
		Splitter	15.0	Abrasive	5.0
		Pump (abrasive recirculation)	5.0		
		Wire	15.0		
		Torch and cutter	*		
		Total	80.0	Total	45.0

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*Equipment already on hand and therefore not recosted.

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9.0 MANPOWER REQUIREMENTS, REMOVAL RATES AND SCHEDULE ESTIMATES

Each of the demolition methods under consideration can be broken down into the following job site activity sequence:

- Preparation and setup
- Major demolition process
- Auxiliary or follow-up demolition process
- Demolition product and waste removal
- Teardown, equipment removal and final cleanup.

These areas of activity were considered for each of the ten demolition/removal options selected in Section 5 and discussed in Section 6. The process rates and parameters, manpower requirements, and durations were identified or estimated for each activity, assuming that all work is done "in-house". Cutting, drilling, and removal rates are based upon References 4 through 8 and personal telephone contacts with Park Owen of the Remedial Action Program Information Center at Oak Ridge, and with several equipment suppliers and contractors active in large-scale concrete demolition work.

The results of these studies are summarized in Table 4.

Preliminary and supporting engineering, supervision, administrative, and reporting support services labor is not included in Table 4 as this cost is estimated to be essentially the same for all methods. The crew sizes shown include job site mechanics, operators, and all support personnel necessary for the immediate task. Each has been costed at $55/man-hour, irrespective of organizational affiliation.

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Table 4. Demolition Labor and Schedule Summary (Sheet 1 of 2)

Item \ Demolition Method	Controlled Blasting	Breaker Ram	Flame Cut	Splitter	Expansive Compound	Circular Saw	Core		Laser	Abrasive Water Jet	Wire Cut	
							Stitch Drill	Large			One Shift	24 hr
Preparation and Setup												
Crew size (EP)	4	4	4	4	4	4	4	4	6	4	6	6
Duration (days)	5	5	10	5	5	10	10	10	10	10	10	10
Labor Load (man–hr)	160	160	320	160	160	320	320	320	480	320	480	480
Major Process												
Process	**Drill 1 in. Blast Holes**	**Breaker Ram**	**Flame Cut**	**2.5 in. Drill**	**2 in. Drill**	**Saw**	**4 – 4 in. Drills**	**4 – 30 in. Corers**	**Laser Burn**	**Two Jet Cutters**	**Drill, Thread Wire, and Cut**	
Rate	1	1	6	1	1	5.5	0.6	0.15	6	5	4.8	4.8
Units	ft/hr	yd3/d	ft2/hr	ft/hr	ft/hr	ft2/hr	ft/hr	ft/hr	ft2/hr	ft2/hr	ft2/hr	ft2/hr
Total	840	26	5,750	840	840	5,750	5,000	1,250	5,750	5,750	5,750	5,750
Units	ft	yd3	ft2	ft	ft	ft2	ft	ft	ft2	ft2	ft2	ft2
Crew Size (EP)	3.75	2.75	2.75	3.75	3.75	2.75	5.75	5.75	2.75	3.75	3.75	3.75/2
Duration (days)	130	58	200	130	130	215	260	260	200	240	250	150
Labor Load (man–hr)	3,900	1,276	4,400	3,900	3,900	4,730	11,960	11,960	4,400	7,200	7,500	9,300
Auxiliary Process												
Process Type	**Charge, Blast, and Cut**	**Cut Rebar and Embeds**	**–**	**Split and Cut Embeds**	**Charge and Cut Embeds**	**Corner Drill, Split and Cut**	**Split and Cut Embeds**	**Split and Cut Embeds**	**–**	**–**	**Separate and Clean Out Corners**	
Crew size (EP)	2.5	4.5	–	2.5	2.5	4	4	4	–	–	4	4
Duration (days)	5	55	–	48	48	15	15	15	–	–	15	15
Labor load (man–hr)	100	1,980	–	960	960	480	480	480	–	–	480	480

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Table 4. Demolition Labor and Schedule Summary (Sheet 2 of 2)

Item \ Demolition Method	Controlled Blasting	Breaker Ram	Flame Cut	Splitter	Expansive Compound	Circular Saw	Core		Laser	Abrasive Water Jet	Wire Cut	
							Stitch Drill	Large			One Shift	24 hr
Removal												
Primary Waste Forms [a]	Rubble[b]	Rubble	Chunks, Filters, and Slag	Rubble[b]	Rubble[b]	Blocks, Rubble, and Water	Blocks, Cores, and Rubble[b]	Cores and Rubble[b]	Blocks, Filters, and Slag	Blocks, Abrasive, and Water	Blocks, Abrasive, Corner Rubble, and Water	
Crew Size (EP)	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
Duration (days)	65	65	65	65	65	65	65	65	65	65	20	20
Labor Load (man-hr)	3,380	3,380	3,380	3,380	3,380	3,380	3,380	3,380	3,380	3,380	1,040	1,040
Teardown and Cleanup												
Crew size (EP)	4	4	4	4	4	4	4	4	4	6	4	4
Duration (days)	2	5	2	2	2	2	2	2	5	5	5	5
Labor load (man-hr)	64	160	64	64	64	64	64	64	160	240	160	160
Totals												
Working days	207	188	277	250	250	307	353	353	280	320	300	200
Labor load (manhr)	7,604	6,956	8,164	8,464	8,464	8,974	16,204	16,204	8,420	11,140	9,660	11,460
Labor cost at $55/hr ($000)	418.20	382.60	449.00	465.50	465.50	493.60	891.20	891.20	463.10	612.70	656.30	755.30
Duration at 5 d/wk (calendar days)	290	264	390	350	350	430	495	495	392	448	420	280
Weeks	42	38	56	50	50	62	71	71	56	64	60	40

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[a] All methods will have some operational materials, tooling, and equipment as radioactive (R/A) waste.

[b] May have residual drilling lubrication and dust control water as R/A waste.

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10.0 DEMOLITION METHOD RANKING AND RECOMMENDATIONS

As stated in the objectives for this study (Section 2), ALARA considerations and the current state of remotely performed demolition equipment and methods development, as well as cost and schedule requirements and capabilities, must be evaluated and ranked before recommendations and final method selection can be made.

Comparative equipment and material costs were developed for this task and are summarized in Section 8 of this report. Manpower levels, removal rates, elapsed times and labor cost estimates were then developed for each of the candidate methods as summarized in Section 9. Each of these summaries can readily be arranged in ranking order for the parameters of interest, cost and schedule.

ALARA considerations are more difficult to rank. Sections 4, 5, and 7 have already touched upon ALARA parameters and have eliminated seven potential demolition scenarios, all at least in part because of ALARA. However, ranking of the remaining cases is a more difficult task in that the exact detailed procedures and sequences for each case have not been developed and the exact radioactivity levels and exposure fields are not yet known. It was decided after several attempts to quantify the radiation exposure potential for each scenario, that the best relative measure for use at this time would be the cumulative man-hours of demolition work performed in the immediate vicinity of the radiation sources for each case. Thus the method requiring the fewest total demolition/exposure man-hours would be ranked first for this category.

Overall combined ranking of the various methods then becomes merely the addition of the selected ranking parameters using assigned weighting factors to arrive at a single weighted value for each case. As neither cost nor schedule constraints have yet been established for this activity, and detailed quantitative exposure values are unknown at this time, equal weighting of the individual total cost, schedule and demolition/exposure man-hour (ALARA) rankings was assumed in calculating the overall ranking positions. The method of ranking can be refined as the exact procedural steps and the workstation radiation environments become better defined.

Individual ranking positions and calculated values for relative cost (sum from Table 3 and Table 4), schedule and exposure man-hours (from Table 4) are shown in

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columns one through six of Table 5. Column seven lists the sum of the three individual ranking numbers (columns 1, 3, and 5) for each method. These sums were used to establish the nonweighted ranking order used for compiling the table.

A second comparative number was then calculated for each demolition method as shown in column eight. This number is the adjusted product of the numeric values in columns two, four, and six, and is in effect a form of a weighted value. This simplified approach gives relative numbers close to unity which reflect the case-to-case spreads for each of the three ranking parameters, and thereby gives each case an overall relative ranking. Note that both columns seven and eight have numeric values in the same ascending order as the ranking order listing. The column eight numbers, however, give a clearer indication of the net case-to-case spacing.

10.1 Recommendations

Based upon the results summarized in Table 5 it is recommended that:

1. The Breaker Ram demolition method be selected for the Building 059 cast-in-place concrete shield.
2. A survey be undertaken to locate the best Breaker Ram tools and carriage or mount and arm equipment available for the job.
3. A cost-effectiveness study be undertaken to evaluate the best way of performing the work. Possible ways of organizing are:
   - With in-house labor and purchased or leased equipment.
   - With contractor equipment and operators supplementing in-house efforts.
   - By a turnkey contract for some portion or all of this task.

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Table 5. Demolition Method
Overall Relative Ranking Summary

Ranking Order	Demolition Method / Column Number	Cost		Schedule		Exposure		Rank	Relative Ranking Number
		Rank	($000)	Rank	Weeks	Rank	Man-hr		
		1	2*	3	4	5	6	7 (1 + 3 + 5)	8 (2 x 4 x 6 x 10^{-8})
1	Breaker ram	2	570	1	38	1	7,000	4	1.54
2	Expansive compound	1	505	3	50	2	8,500	6	2.15
3	Rock splitter	2	570	3	50	2	8,500	7	2.42
4	Wire cutting (5 days – 3 shifts)	5	755	2	40	4	9,060	11	2.74
5	Circular saw	3	590	5	62	3	8,975	11	3.28
6	Wire cutting	4	660	4	60	5	9,660	13	3.83

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*Sum of equipment, material, and labor costs (see Tables 3 and 4)

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11.0 REFERENCES

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